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Influence of Cochlear Implantation on Balance Function in Pediatrics

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ABSTRACT

Background and Objective: Patients with profound Sensorineural Hearing Loss (SNHL) are susceptible to vestibular disturbances following Cochlear Implant (CI) surgery. This study aimed to evaluate vestibular dysfunctions following unilateral CI in the congenitally deaf children.

Methods: This was a cross-sectional study conducted on 24 children (mean age: 10.56 ± 5.49 years old) who underwent unilateral CI and 24 age-matched controls (mean age: 11.13 ± 6.21 years old). Vestibular functions were assessed by Vestibular Evoked Myogenic Potential (VEMP) and Computerized Dynamic Posturography (CDP). The VEMP test was performed for otolith's function (especially saccule) evaluation. Sensory Organization Test (SOT) protocol of CDP was also utilized to differentiate the role of various sensory systems contributing to postural stability. In addition, total equilibrium score was calculated. The variables were comparatively assessed between the two groups.

Results: The mean p13-n23 amplitude in the CI users was significantly lower than the controls ($p<0.05$). However, the two groups showed no significant difference in cVEMP latency values ($p>0.05$). The SOT analysis revealed that 45.83% (11/24) of the CI subjects had some kind of sensory abnormalities: 7 cases (29.17%) vestibular, 2 cases (8.33%) visual, 2 cases (8.33%) vestibular and somatosensory involvements. Furthermore, total equilibrium score was significantly reduced in implanted group than the controls ($p<0.001$). At least, 70.59% (12/24) CI patients showed abnormal values in the CDP or cVEMP examinations.

Conclusion: This study shows functional vestibular impairments in children who underwent CI. These patients showed significantly increased postural instability which was more evident in dynamic conditions. These findings provide the basis for better pre-operative counseling and postoperative vestibular rehabilitation to CI recipients.

Keywords: Cochlear implant, vestibular evoked myogenic potential, dynamic posturography.

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INTRODUCTION

Cochlear Implantation (CI) is commonly used worldwide as an effective procedure of restoring hearing in patients with profound sensorineural hearing loss (SNHL)[1-4]. Beneficial impacts of CI on auditory performance, speech and language comprehension have been well documented[5]. However, CI surgery can induce vestibular impairments due to anatomical proximity of the cochlea to the vestibular end organs[6,7]. Recent evidence has demonstrated a relatively wide range (0.33% to 75) of vestibular impairments associated with CI[8-10]. Different mechanisms have been proposed to explain vestibular dysfunction during or following CI surgery, including electrical stimulation by the prosthesis, direct trauma following electrode placement, foreign body reaction or labyrinthitis, and endolymphatic hydrops[10-13]. Maintaining our body balance in upright stance necessitates the central processing of input signals from the vestibular, somatosensory and visual systems, resulting to a specific motor response via the adjustments of dynamic and static postures[14]. Therefore, the inner ear alteration following the implant insertion may lead to postural disturbances just after the operation and after the activation of the prosthesis[15]. Despite probable inner ear damage produced by the CI, enhancement of the postural stability has been reported in these patients after the surgery. These patients frequently report varying forms of unsteadiness or dizziness after surgery that their symptoms may improve across time through the compensation, substitution, or habituation processes[16]. However, several studies revealed that postural control remains impaired after implantation without any effect of hearing restoration even five years post-operation[17]. Computerized Dynamic Posturography (CDP) is a set of tests used to objectively measure the relative contributions of proprioception, visual, and vestibular inputs to postural stability, under either dynamic or static situations[18,19]. Cervical Vestibular Evoked Myogenic Potential (cVEMP) is also an objective and non-invasive clinical technique to assess the integrity of the inferior vestibular nerve and saccule[20]. Considering the relatively high prevalence of pediatric CI, it is necessary to determine the potential risks of this surgery on the vestibular system. The current study aimed to evaluate the impacts of CI surgery on vestibular function and postural stability in pediatrics who underwent unilateral CI using CDP and cVEMP assessments.

MATERIALS AND METHODS

Participants: The study group consisted of 24 patients (males: 14; females: 10; mean age: 10.56 ± 5.49 years; age range: 8-14 years) with congenital bilateral profound SNHL. In addition to the CI group, the control group 24 subjects (males: 12; females: 12; mean age: 11.13 ± 6.21 years; range 8-14 years) with normal hearing who underwent general anesthesia without ear operation.The inclusion criteria for the CI participants were (1) age range from 1.5 to 3.5 years at the time of surgery, (2) congenital bilateral profound SNHL, (3) complete insertion of cochlear implant electrodes into the cochlea, and (4) regular attendance at auditory training sessions. Patients with cognitive dysfunctions or with cochlear deformities were excluded. Furthermore, subjects who had a history of medical or neurological disorders affecting dizziness symptoms (ototoxicity, otitis media) were excluded from the study. No patients in either group complained of dizziness or vertigo before the operation. They also had normal tympanic membrane and middle ear function (Type An tympanogram). All cochlear implant operations were performed by the same experienced otologist's team. The CI operation was conducted using the round window method following a regular mastoidectomy with posterior tympanotomy. The electrode insertion was carried out with as little pressure as possible.The experimental protocol of this study was approved by the local ethics committee (registration code: IR.AJUMS.REC.1393.290) which were in accordance with the ethical standards and regulations of human studies of the Helsinki Declaration.

Procedures: Computerized Dynamic Posturography (CDP): CDP was conducted using an EquiTest system (NeuroCom International, Clackamas, Oregon, United States). The sensory organization test (SOT) component of CDP was carried out to identify abnormalities in the subject's use of the sensory inputs involved in postural stability: vestibular, visual, and somatosensory. During SOT, subject's balance function was assessed under 6 separate sensory conditions (Table 1). The averaged value of 3 trials was considered for each test condition. After each assessment, the balance score was expressed as a percentage between 100% (perfect stability) and 0% (fall). The SOT composite equilibrium (CE) score was computed by averaging the scores for each condition, a measure of the overall performance in terms of postural stability.

Vestibular Evoked Myogenic Potentials (cVEMPs): The cVEMP test was carried out using Epic Plus (Labat, Italy) system. For cVEMP recording, each subject was lying on a comfortable chair with an inclination angel of 300 from the horizontal plane. cVEMPs were recorded from an electrode montage including a non-inverting

Table 1: Sensory test conditions (C1-C6) of sensory organization test.

Test Condition	Vision	Surround	Platform
C1	Eyes Open	Fixed	Fixed
C2	Eyes Closed	Not Applicable	Fixed
C3	Eyes Open	Sway-referenced	Fixed
C4	Eyes Open	Fixed	Sway-referenced
C5	Eyes Closed	Not Applicable	Sway-referenced
C6	Eyes Open	Sway-referenced	Sway-referenced

electrode situated on the sternocleidomastoid muscle, and a ground electrode positioned on the forehead. An inverting electrode was also placed on the manubrium of the sternum. The stimulus parameters used were as follows: 500 Hz tone burst (0 ms plateau time and 4 ms rise/fall time), and repetition rate of 4.1/s. The acquisition parameters were as follows: filter setting 10 Hz-2000 Hz, amplification rate ∊5000, time window 70 ms, and number of sweeps 200. The first positive and second negative peaks of biphasic cVEMP waveforms were marked as wave p13 and n23, respectively. The absolute p13 and n23 latencies (ms) and p13-n23 amplitude (μv) were measured at an intensity of 95dB nHL.

Statistical Analysis: Data were expressed as mean ± standard deviation (SD). Comparisons between means of SOT and cVEMP parameters between the two groups were carried out using paired sample t -tests. The relationship between the two vestibular tests was evaluated using Spearman's rank correlation coefficients. Significance level was taken as p-value<0.05. The SPSS software package (ver. 23.0, Chicago, IL, USA) was used to carry out all statistical analysis.

RESULTS

The cochlear implant electrodes were placed in the right ear of 17 participants (70.83%). The CDP measures showed a poorer overall balance performance, as documented by the composite scores, in CI patients than the controls (Wilcoxon's rank test, p=0.009), but it was not homogeneous across all CDP conditions. Reveals that CI patients displayed lower SOT scores than the controls in C5 and C6 conditions (paired sample t-test, p<0.001), while in other conditions there were no significant differences between both groups (Table 2). Detailed analysis of the individual SOT conditions exhibited that 45.83% of CI patients (11/24) had some kind of sensory abnormalities, including 7 cases (29.17%) vestibular, 2 cases (8.33%) visual, 2 cases (8.33%) vestibular and somatosensory involvements. The cVEMP response was recorded in all cases. The mean p13-n23 amplitude in CI patients was significantly reduced than the control group (p<0.001) (Table 3). However, no significant differences were found in any of peak latencies between the control and CI groups. The SOT and cVEMP test results in CI recipients are presented in Table 4. Our findings demonstrated that 12 (70.59%) CI subjects demonstrated abnormal findings at least in one of the vestibular tests. In addition, 5 (29.41 %) patients displayed both VNG and cVEMP abnormalities. We found a moderate level of agreement (Kappa=0.48, p=0.015) between the results of VNG and cVEMP tests (Table 4).

DISCUSSION

This study aimed to evaluate vestibular dysfunctions following unilateral CI in the congenitally deaf children. Our findings revealed that patients with unilateral CI showed poorer balance performance, as documented by the composite scores, compared to control subjects, but it was not homogeneous across all CDP conditions. CDP is a simple, non-invasive, and objective procedure for vestibular function assessment. This test is repeatable and can be better tolerated in small children. In addition, CDP did not necessitate any sedation, or electrode's placement[21-24]. We found that in non-conflicting situations, with a fixed support, the postural performance of the CI cases was rather similar to the healthy individuals

Table 2: The posturographic results of cochlear implanted (CI) patients compared with controls.

Parameter	Group		*p-value*
	Control	CI	
SOT1	93.47 (± 2.68)	92.87 (± 2.89)	0.381
SOT2	91.87 (± 3.09)	89.57 (± 5.37)	0.227
SOT3	89.45 (± 6.15)	86.22 (± 4.70)	0.138
SOT4	84.75 (± 6.34)	81.57 (± 6.43)	0.156
SOT5	74.39 (± 9.87)	61.39 (± 8.56)	p<0.001
SOT6	67.45 (± 13.34)	59.28 (± 10.34)	p<0.001
Composite Score	82.78 (± 12.19)	70.14 (± 11.05)	p<0.001

Table 3: Vestibular Evoked Myogenic Potential (VEMP) results of cochlear implant (CI) group compared with the controls.

Parameter	Group		p-value
	Control	CI	
p13 latency (ms)	13.25 (± 4.13)	12.95 (± 3.71)	p=0.143
n23 latency (ms)	21.65 (± 3.79)	22.07 (± 4.28)	p=0.214
Amplitude (μv)	65.43 (± 27.19)	38.14 (± 19.25)	P<0.001

Table 4: Agreement between VEMP and SOT test results in cochlear implanted patients.

		SOT		
		Normal	Abnormal	Total
VEMP	Normal	11	4	15
	Abnormal	2	7	9
Total		13	11	24

(C1 to C3 conditions of SOT test). This finding can be explained by this fact that the primary element responsible for maintenance of stance in these conditions is that of either vision or proprioception sensory systems. However, Bernard-Demanze et al.[25] reported that postural performance of the CI recipients, especially in eye closed condition, is noticeably lower than the healthy subjects. Our study indicated that the differences between the CIs and controls was strongly evident in situations that primarily emphasize on vestibular inputs for maintenance of stance (C5 and C6). That means the patients using CI may demonstrate increased degree of postural instability in dynamic situations. It has been suggested that dynamic processes emphasize on substitution and integration of information originating from the different neural network components that contributing in the balance control system [26,27]. Electrical stimulation provided by the CI can influence not only auditory processes, but also vestibular processes. Then, CI stimulation play an important role in triggering neural plasticity, which integrated the neural networks contributing to postural stability[28]. However, Buchman et al.[10] showed that unilateral implantation rarely affects vestibular system; on the contrary, CI patients reported notable improvements in postural stability, with an additional positive effect on prosthesis activation in music. Parietti-Winkler[29] study also showed lower postural performances in the CI patients (n=10, age range: 27 to 72 years) than in the control group (n=10). These differences were more pronounced in C1, C3, C5, and C6 conditions. In contrast to our findings, reported that single-sided CI does not adversely influence dynamic postural stability 5 weeks post-CI operation. They evaluated the dynamic postural stability in 23 adult CI recipients (mean age: 70; age range: 31-83 years) using a Functional Gait Assessment (FGA) scale. The FGA test has been designed to detect changes in gait performance in subjects with vestibular disorders, and especially to assess risk of fall. Buhl et al.[30] findings demonstrated no significant mean difference between the pre- and post-operative FGA scores. Temporal bone studies have demonstrated that insertion of electrodes into the scala vestibuli may lead to morphological lesions of the cochlear partition, osseous spiral lamina, or vestibular receptors. The saccule was the most commonly affected vestibular receptor, followed by the utricle and the semicircular canals [31,32]. The cVEMP assessment is an easy-to-use approach to evaluate inferior vestibular nerve and saccular integrity. Furthermore, the cVEMP can be employed for the assessment of the growth of vestibulo-collic reflex in healthy children[33-35]. In the present study, cVEMP amplitudes were remarkably larger in the control group than CI recipients. However, there was no significant difference in peak latencies (n13 and p23) between the CI and control groups. Our study indicated the evidence of saccular injury in 37% (9/24) of the patients, which supports the findings of Melvin et al. [36] who reported a saccular abnormality in 31.25% (5/16) of implanted ears. Contrary to our findings, Basta et al.[3]7 reported a higher incidence of saccular dysfunction (62.5%) in patients who received CI. In Krause et al.[38] study, 21 (45%) implanted subjects who reported vertigo or balance disturbances after implantation. However, the damaged vestibular function did not associate with vertigo symptoms. The current study indicated a moderate level of agreement between the results of VNG and cVEMP evaluations. Katsiari et al.6 evaluated unilaterally CI patients (n=20) before the surgery, and one and six months after the surgery using cVEMP and caloric recordings. Their findings demonstrated a significant difference in the canal paresis and cVEMP waveform abnormality rate between the repeated vestibular assessments in the implanted ear, whereas in the non-implanted ear no statistical difference was observed.

CONCLUSION

The present study clearly shows vestibular dysfunctions in children who underwent CI. The results of this study highlight the importance of counseling of parents and children concerning the vestibular consequences of cochlear implantation.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest on publishing this paper.

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